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RAPID H_2 PURGE WITH CO_2 FOR SAFER PLANT OPERATIONS—TEST RUN RESULTS

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ABSTRACT

Hydrogen cooled generators need to undergo carbon dioxide (CO_2) purging before being placed into service and when taken offline. This process typically takes 4 to 12 hours, and can take as long as 36 hours in extreme cases, to fully and safely purge a generator. Reducing the volume of hydrogen gas in these generators is essential for reducing the risks of explosions. If these purge times could be shortened, improvements in safety, shorter outages, and increased production could be realized. This paper describes plant testing of a CO_2 Fast Degas purging system for hydrogen cooled generators. Results from eight test runs at two different plants are presented in tabular and graphical form. Mean reduction from pure hydrogen to less than 4% hydrogen was 39.8 minutes, while maintaining CO_2 temperatures above 80°F (27°C). This eliminates the possibility of CO_2 freeze up, and reduces the stress on the piping and the detrimental effects on the generator from extreme temperature swings that occur when CO_2 is de-pressurized. These rapid purge rates were accomplished while maintaining the generator pressure within a set range. In order to achieve the minimum purge time, it is critical that mixing of the two gases be minimized during the purge operation. By utilizing the slope of the graphs provided, the system was optimized to minimize purge times to reach safe levels. Tests were performed on both purging operations, replacing hydrogen with CO_2 and replacing air with CO_2. Samples to analyze the generator gas purity were taken from the vent line using multiple thermal conductivity purity instruments to assure accurate results. The system was tested in both automatic and semi-automatic modes of operation. The fast degas system was found to significantly reduce generator purge times, reducing down time, and improve operator efficiency, positively affecting the overall safety profile of the plant.

INTRODUCTION

Large electric generators are cooled with hydrogen due to the physical properties of the gas. Hydrogen has the lowest density and the highest specific heat of any gas, making it well suited for cooling applications. One disadvantage to using hydrogen is its wide explosive range—4% to 75% hydrogen in air [1]. Every precaution must be taken to prevent the hydrogen from mixing with air. To avoid forming explosive mixtures, an inert gas is used as a barrier between the hydrogen and air. The most common inert gas barrier is carbon dioxide (CO_2), which is widely available and relatively inexpensive.

Generator startup procedures involve removing air from the generator case by displacing it with CO_2. CO_2 is denser than air, so it is introduced into the bottom of the generator while the top is opened to the vent, permitting the lighter air to escape. The purity of the exiting gas is analyzed to indicate when the air has been completely displaced. To fill the generator with hydrogen, the flow direction is reversed. Hydrogen is lighter than CO_2, so it is introduced into the top of the generator while the bottom is opened to the vent, permitting the heavier CO_2 to escape. The purity of the exiting gas is used to indicate when the generator has reached the intended operating hydrogen purity. These steps are reversed when taking the generator out of service for scheduled maintenance or emergency. This process is known as purging the generator.

Figure 1 A-C represents the purging process when taking a generator offline.

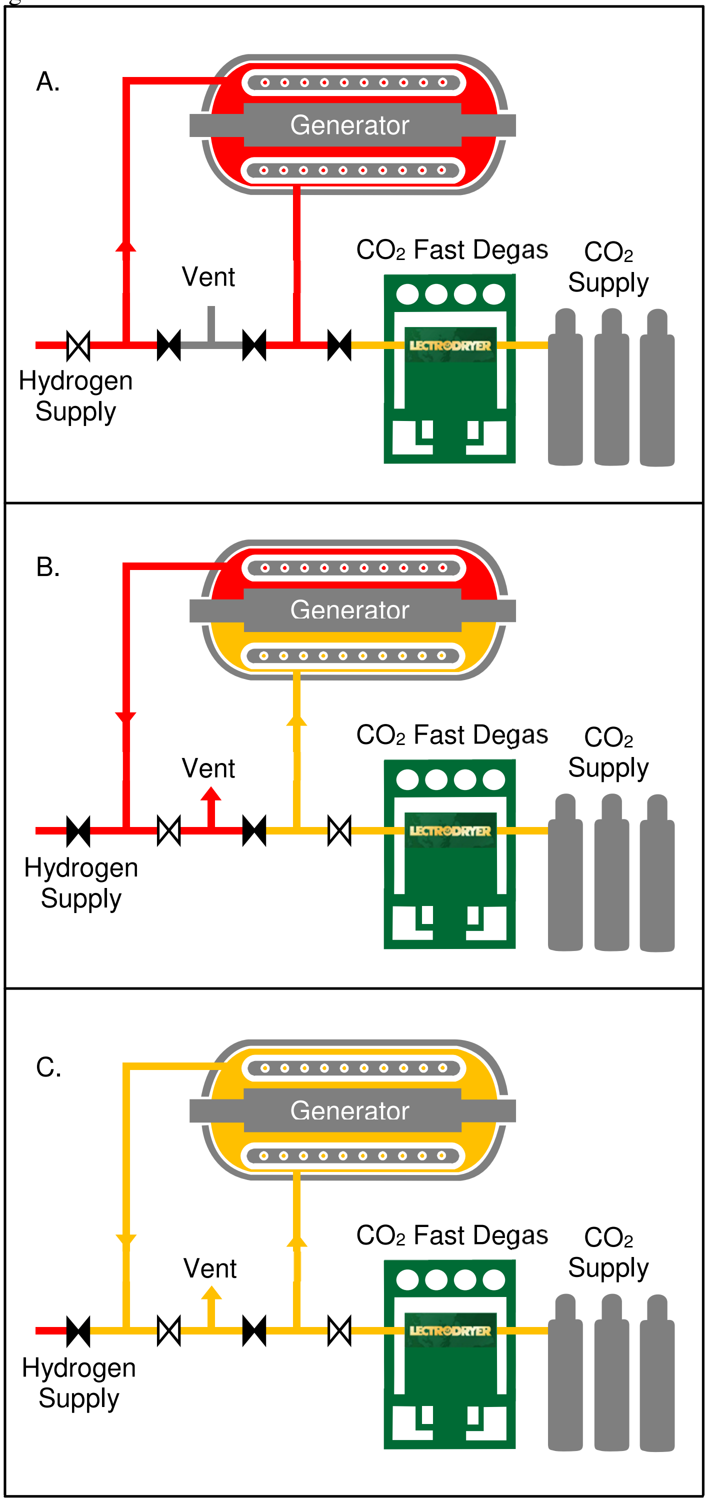

FIGURE 1. SCHEMATIC OF THE PURGE PROCESS TO TAKE A GENERATOR OFFLINE. RED REPRESENTS HYDROGEN. YELLOW REPRESENTS CO_2.

One disadvantage to using CO_2 as the purge gas is that the depressurization of CO_2 is an endothermic process, causing cryogenic temperatures through the Joule Thompson Effect [2]. When depressurized to atmospheric pressure, CO_2 can achieve temperatures as low as -109°F (-78°C). Under these conditions, dry ice (solid CO_2) may form, reducing or even blocking the flow of purge gas into the generator. Furthermore, these cryogenic temperatures may be harmful to piping and generator components. Carbon steel components may become brittle, and widely accepted weld procedures are not intended for applications below -20°F.

To prevent damage, minimize risk, and reduce dry ice formation, CO_2 purging has traditionally been done very slowly. The purging process often takes 4-12 hours, with extreme cases taking 36 hours or longer. These hours have a significant financial impact through lost revenue and operator expenses, ranging from $10,000 per hour for a planned outage up to $100,000 per hour for an unplanned outage during peak season.

If these purge times could be significantly shortened, improvements in safety, reduced outage times, and increased production could be realized. Access to faster purge capabilities would be invaluable in emergency situations requiring the hydrogen to be displaced quickly (bearing fire, natural disaster, etc.). Furthermore, faster purge capabilities would allow a single work shift to perform purging. This could prevent miscommunication during shift changes—a recognized contributing factor in recent generator accidents.

The purpose of this paper is to present evidence that a hydrogen cooled generator can be purged both quickly and safely by employing the appropriate equipment and procedures. Data presented here is for both CO_2 purge steps: taking the generator offline (removing hydrogen) and putting the generator back in service (removing air).

TEST DATA

Eight tests were performed at two different generating stations using the Lectrodryer CO_2 Fast Degas System. The locations were Florida Power & Light Company's (FPL) Cape Canaveral Energy Center (Cocoa, Florida) and East Kentucky Power Cooperative's (EKPC) Dale Power Station (Clark County, Kentucky). Cape Canaveral Energy Center is a natural gas fired combined cycle plant, and the data presented here is from units 1, 2 & 3 (265 MW, Siemens 8000H generators). Dale Power Station is a coal fired plant and the data presented here is from unit 4 (80 MW, GE generator). The tests were performed between February and August of 2015 in cooperation with the plant personnel. The generators were on turning gear for these tests.

The results are presented as the percent purity of the exiting gas as a function of time. The purity measurements at Cape Canaveral were made with two independent instruments, Siemens Calomat 6s. These instruments measure thermal conductivity relative to calibration span and zero gases to indicate the sample's purity. The variance between the two instruments was negligible. The purity measurements at Dale Power Station were made with two independent instruments, a portable purity analyzer and a gas density blower. The portable analyzer measured thermal conductivity relative to calibration span and zero gases to indicate the sample's purity. The gas density blower measures the sample's density relative to air used in calibration. The variance between the two instruments was negligible.

The purity data from the test runs is shown in Table 1. The generator purge was considered complete and the test concluded when the hydrogen purity reached 4% or lower when coming offline (displacing hydrogen), or when the CO_2 purity reach 96% when coming online (displacing air). Previously, purging at Cape Canaveral took an average of 12 hours.

The temperature of the CO_2 purge gas was also measured. The outlet temperature from the CO_2 Fast Degas System was maintained at 65°F (18°C) or greater during all tests. Figure 2 shows a typical temperature profile of the CO_2 during a purge (data from Dale Power Station).

Graphs of the exiting gas's purity versus purge time are shown in Figure 3 and 4. These figures can be used to interpret the effectiveness of the purge by analyzing the purity's slope. By keeping the purity near 100% at the beginning, pure hydrogen is being removed from the generator and minimal mixing is occurring. Once the purity begins to decline, a steeper slope is preferred—this indicates a narrower boundary layer between the CO_2 and hydrogen and more effective displacement (less CO_2 needed). The graph of testing at Cape Canaveral (Figure 3) reached less than 4% hydrogen (purge complete) within 39 minutes. The tests at Dale Power Station (Figure 4) reached less than 4% hydrogen within 31 minutes.

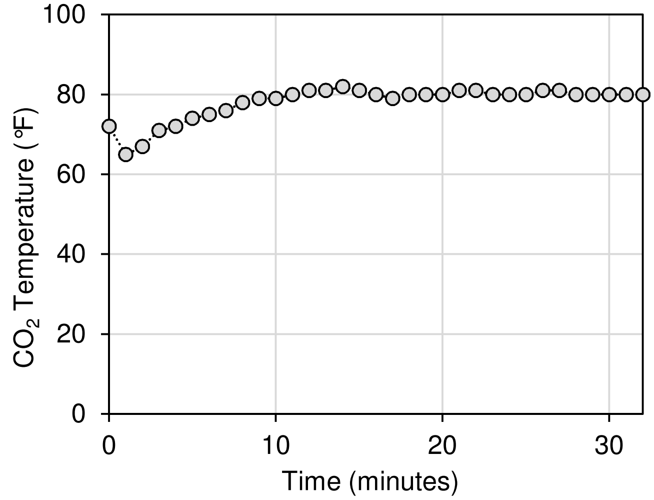

FIGURE 2. CO_2 TEMPERATURE VERSUS TIME, EKPC DALE POWER STATION (8-14-2015)

TABLE 1. SUMMARY OF GENERATOR PURGING AT FPL CAPE CANAVERAL AND EKPC DALE POWER STATION

Test	Utility	Station Name	Gen.	Gen. Mfr.	Gen. Volume (ft^3)	Purge Type	Time to 10%	Time to 4%
1	FPL	Cape Canaveral	3	Siemens	2829	H2 to CO2		120 min †
2	FPL	Cape Canaveral	3	Siemens	2829	Air to CO2		60 min
3	FPL	Cape Canaveral	1	Siemens	2829	H2 to CO2	36 min	39 min
4	FPL	Cape Canaveral	1	Siemens	2829	Air to CO2	43 min	45 min
5	FPL	Cape Canaveral	2	Siemens	2829	Air to CO2		60 min ‡
6	EKPC	Dale	4	General Electric	1600	H2 to CO2	24 min	33 min
7	EKPC	Dale	4	General Electric	1600	H2 to CO2	22 min	31 min
8	EKPC	Dale	4	General Electric	1600	H2 to CO2	22.5 min	31 min

† Initial equipment start-up and test run
‡ First equipment operation performed by plant staff alone

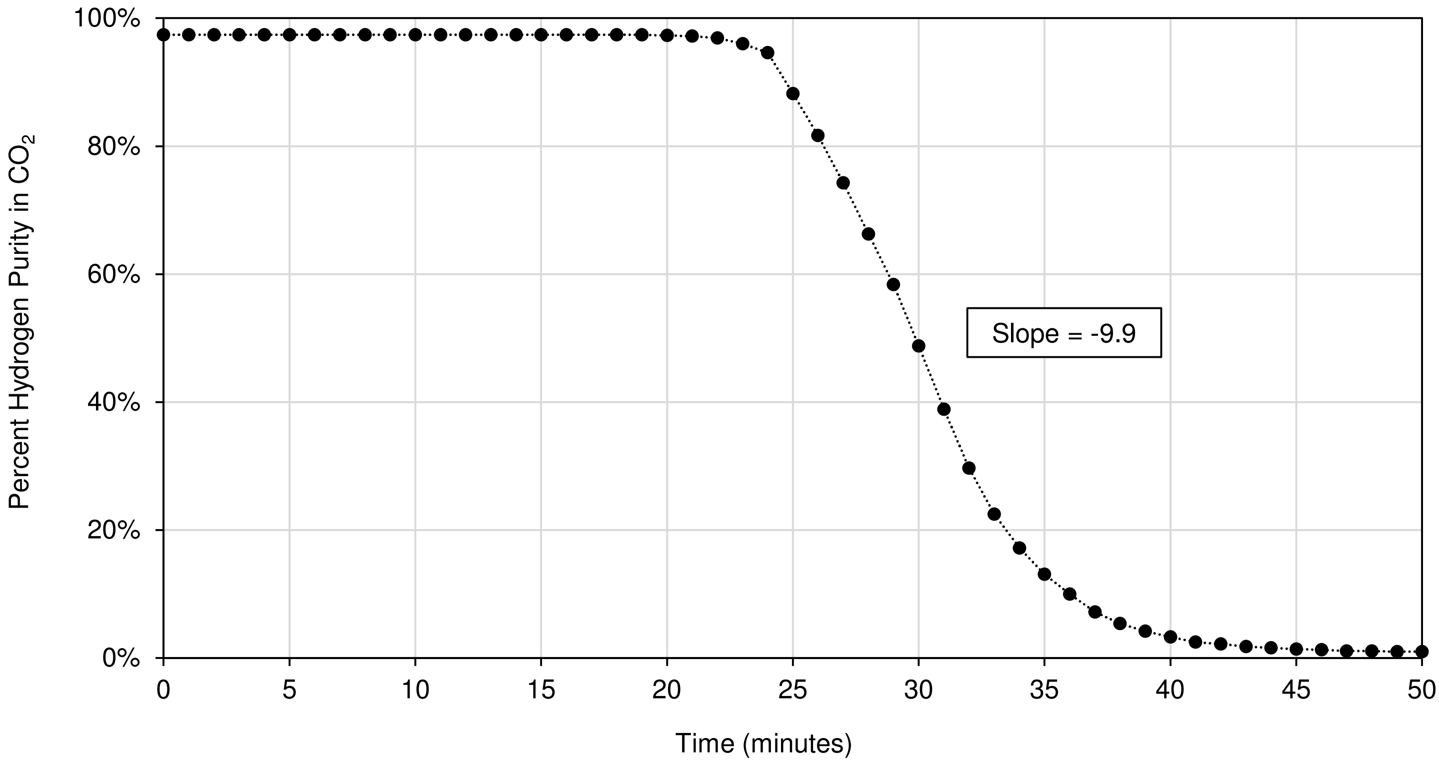

FIGURE 3. PERCENT HYDROGEN IN CO_2 VERSUS TIME AT FPL CAPE CANAVERAL, UNIT 1 (3-13-2015)

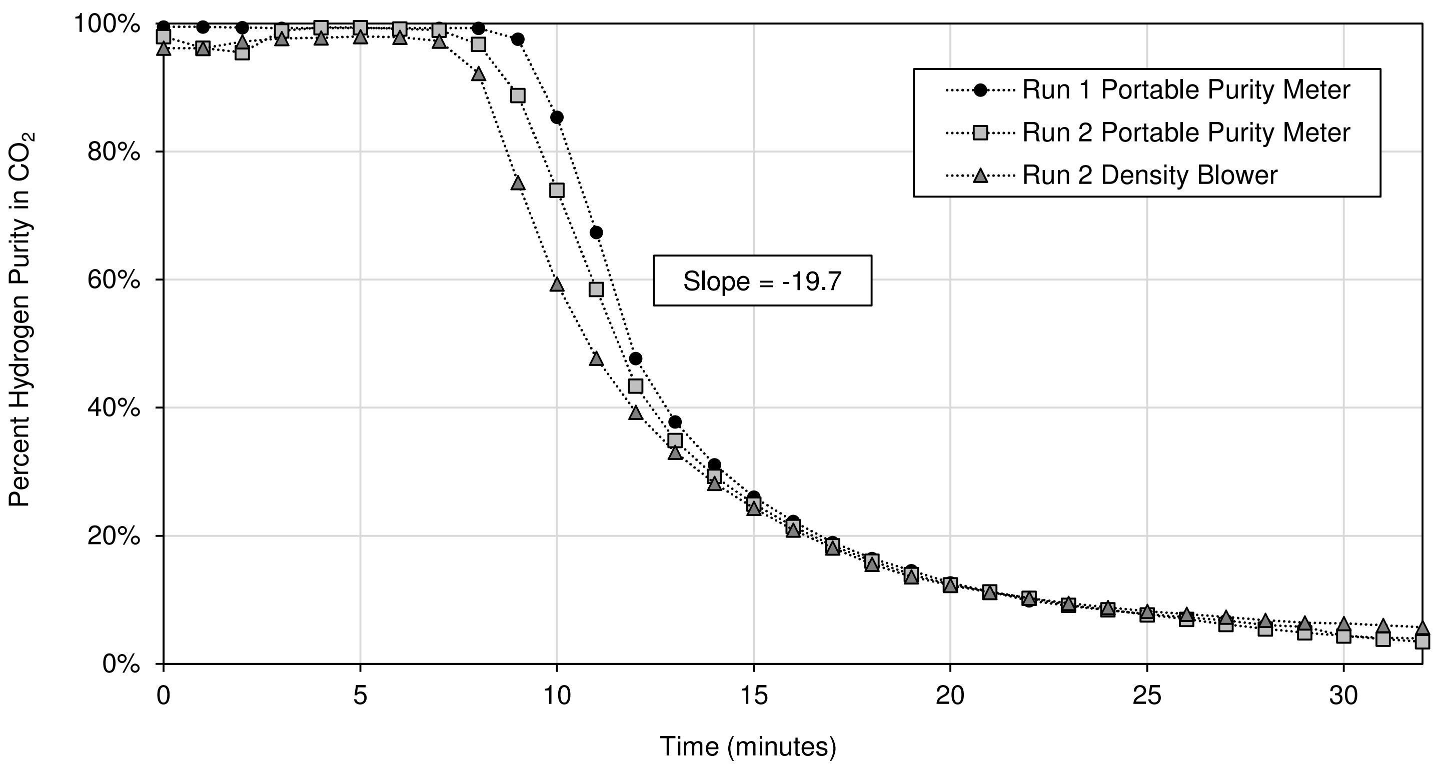

FIGURE 4. PERCENT HYDROGEN IN CO_2 VERSUS TIME AT EKPC DALE STATION, UNIT 4 (8-14-2015)

CONCLUSION

The data presented supports the claim that generators can be rapidly purged with CO_2 by employing the appropriate equipment and procedures (Figure 5). The tests also confirm the ability to purge generators with minimal mixing of the gases. Most generators can be purged in 40 minutes or less by using the same equipment and procedures.

The three tests performed at Dale Power Station used additional equipment to support the purging process. A fully automated system allowed the push of one button to initiate and complete the purge process, going from 98.5% to less than 4% hydrogen in CO_2 in approximately 30 minutes. With this configuration, the entire purge process could be done from the control room. Not only does this minimize labor, it removes opportunities for human error (opening/closing the wrong valves). Furthermore, controlling the purge process from the control room reduces the need to send operators into a hazardous situation to purge the generator in the event of an emergency (bearing fire, natural disaster, etc.).

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[1] Warren, Peter. Hazardous Gases and Fumes – A Safety Handbook. Elsevier, 1997, p. 96.

[2] Burnett, E. S. "Experimental Study of the Joule-Thomson Effect in Carbon Dioxide", Physical Review Letters, Reviews of Modern Physics, December 1, 1923.

FIGURE 5. LECTRODRYER CO_2 FAST DEGAS